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Simulation And Visualization Opportunities In The Ship Production And Maritime Environment

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ABSTRACT

This paper provides an introduction to the application of commercial off the shelf (COTS) and PC based simulation and visualization software in the ship production and maritime environment. It is intended to assist the shipyard manager, production engineer, naval architect and marine engineer in identifying simulation and visualization opportunities in the areas of production, project management, training, design, and port evaluation for vessel loading/unloading times. The desired features of simulation and visualization software for maritime applications are discussed, and a sample listing of both maritime and non-maritime simulation efforts is provided. In addition to this general discussion, two projects which utilize these technologies are described.

INTRODUCTION

Today, through the evolution of technology, simulation and visualization capabilities have been transferred from expensive main frames and work stations to affordable desk top computers. The software applications themselves have also evolved from specialized one-of-a-kind products to essentially commercial-off-the-shelf (COTS) products. This transformation has resulted in a much broader expanse of application for simulation and visualization technology. No longer are the tools solely used by large corporations, governments, and universities for complex, time consuming problems. Instead they are used by companies of all sizes for applications ranging from plant layout and training to analyzing and evaluating ship systems and sub-systems. The results that are being obtained through the application of these technologies include more informed operators, design optimization options, and, of course, the simple answer of whether or not a concept will work.

In order to provide some insight as to what is required to use these technologies, as well as to provide more detailed information on the benefits that may be obtained, two projects are discussed in detail in this paper. The first project entails the use of simulation software to model the mess line flow for a ship's galley while the second project involves the linking of visualization software with scheduling software. This latter capability allows for the 3-D visualization of ship production schedules, illustrating the effect on ship assembly and erection processes of modifications to that schedule. In addition to these two projects a number of other potential applications for simulation and visualization techniques in the shipbuilding and design arena are identified.

SIMULATION

Simulation can be described as a number of things, yet simply put it is both a process and a tool. It is a process when it is used as a method for modeling a sequence of events, and it is a tool when that model is then used to produce results which can be analyzed. This dichotomy in definition is also shown in the definition provided by *The New Lexicon Webster s Encyclopedic Dictionary Of The English Language* which states:

> *Simulation: a representation of a product, condition, or process in a different medium, e.g., computer, statistical chart, mock-up, esp. for the purpose of analysis.* [1]

In his paper "Introduction To Simulation", presented at the Winter Simulation Conference 1995, Andrew F. Seila, Professor, University of Georgia, concurs with this definition and further indicates that:

> *All simulations are developed to determine system performance under alternative designs or environments, with the objective of optimally designing or operating the system.* [2]

In other words, simulation allows one to experience and analyze a product, condition, or process as if it was actually occurring. This capability is extremely beneficial and has caused simulation to become a leading system analysis method.

Simulation is an excellent tool that can be used to analyze just about any level of system complexity. The complexity of the system is limited only by the person modeling the system, the physical capacity of the computer, and the software chosen for a particular analysis. The system must also be well understood by the modeler prior to being modeled. The analytical results obtained through simulation, and the visual representation of the model, provide an actual approximation of the system and can carry credibility to the actual decision makers. In short, simulation brings a sense of reality to the analysis of a system. Simulation provides the capability of analyzing any stochastic system without regard to its structure or complexity.

Types Of Simulation Software

There are basically four categories of simulation software. These categories, and some example products, are identified below in Table I.

Classification Type	Examples
General Purpose Languages and Simulation Libraries	Fortran, Pascal, C, Algol, etc., and SIMLIB, SIMTOOLS
Simulation Programming Languages	GPSS, SIMSCRIPT
Interactive Simulation Programming Systems	SIGMA, CAPS/ECSL
Visual Interactive Modeling Systems	AutoMod, ProModel, Arena, Witness, SIMFACTORY

Table I. Simulation Software Classifications [2]

As can be seen by examining this table, simulation software products come in a wide variety of packages with a varying number of features and levels of difficulty. Each of these categories has its pros and cons. As an example, the 'Simulation Programming Languages' category provides users with a product that is a standardized simulation language from which to make his or her models. While this tends to provide the greatest amount of flexibility in creating models, whether they be small and simple ones or large and highly complex, this category also requires a lot of effort on the part of users. With products from this category the user not only needs to know the procedures that will define the model, but also needs to know how to:

- Program these procedures in the language of the selected product;
- Create the constructs which will allow information to be retrieved from the model as the simulation runs; and, if desired,
- How to construct graphical images to visually portray the model's processes in action.

Though not as flexible as the *Simulation Programming Languages* category, the *Visual Interactive Modeling Systems* category contains many of the same benefits with a shorter learning curve. At the low end of the spectrum in this category are the *user friendly*, *canned* products which combine a simple to use interface with pre-made modeling features. These products are excellent tools with which to model simple and small processes. At the other end of this category, vendor specific proprietary simulation languages have been added to the product providing them with the flexibility required to model large and highly complex processes. Even at this end of the category, users can still be constrained by the features of the inbred simulation language, as well as his or her own limits in understanding that language.

The exact method of simulation found throughout these categories of products, is still basically one of two types, either *time-independent models* or *stochastic processes*. Simulations involving stochastic processes represent the majority of the models analyzed with simulation procedures. They can also be further subdivided into either discreet event, or continuous simulation.

Discrete Event Simulation. Discrete event simulation is an incremental, or step by step, process where the simulation proceeds from one event to the next. The events can be either time or queue driven, and, either deterministic or stochastic in nature.

When the process is time derived it uses a fixed time step such as seconds, minutes, hours, days, etc., with which to advance the simulation. This method of modeling provides for a *real life* feel to the visualization of the simulated process. *Real life* in this case refers to the fact that the model is advancing as if it was a real time visualization or enactment of the process. In queue driven or variable time step simulation the time spans between events are not visually portrayed. The key word here is *visually portrayed*.

The variables used in discrete-event simulations models are also typically stochastic. This allows the incorporation of statistical probability analysis into the model providing for a much more accurate representation of the modeled events. The more accurate and detailed these stochastic processes are made the more precise the simulation results will be.

Continuous Simulation. Unlike discrete-event simulation, continuous simulation is not an incremental simulation process, but rather a 'start to stop' process that is primarily interested in showing the beginning and end results of the process being modeled. The actual approach taken in these models is to model the system as a differential equation where time is treated as a continuous variable. The solution is obtained by solving the differential equation. An example is using differential equations to construct a predator/prey simulation model.

Simulation Based Design

Although in existence for a number of years, Simulation Based Design (SBD), is a relatively new and up-coming technology that promises great returns. Part of this popularity is due to the rapid advancements in, and the increased availability of, desk top computers. It is a method, or process, that allows for a high degree of concurrent engineering between the design process, the simulation and analysis of the product, and the design decisions being made. In its current computerized format it has been applied to a great variety of problems; from evaluating manufacturing systems to analyzing public services and business processes.

Some areas of application for SBD in the ship design/production arena are shown in Table II.

By modeling and analyzing process flows in a proposed ship design or manufacturing process lane, problem areas, throughputs, and utilization factors can be identified. The simulation model can then be modified to remove the problem and/or enhance and optimize the overall design of the product or process being modeled. With simulation these changes and repeated analysis can be performed a number of times quickly at relatively low cost.

DESIGN – Space Allocation Optimization – Space Arrangement Optimization – Special Evolution Time Studies – Equipment Selection Optimization – Galley & Mess Line Flow Studies – Equipment Selection & Manning Requirement Studies – General Arrangement Studies – Special Evolution General Arrangement Studies – Identify Optimum/Correct Location For Abandon Ship Lifeboat Stations – Evacuation Route Analysis	– Disembarkation Route Analysis – Equipment Selection/Manning Analysis **PROJECT MANAGEMENT** – Schedule Development – Queuing Date Determination – Planning – Acquisition Date Determination **TRAINING** **PRODUCTION** – Shipyard Production Lanes – Shipyard Construction Planning & Work Load Leveling Aid **PORT EVALUATION FOR CARGO OPERATIONS**

Table II. SBD Applications In The Ship Design/ Production Arena

Simulation Software Recommendation. In modeling and analyzing processes involving the construction or design of a ship, or ship portions (e.g. galley area design and utilization), where the overall process to be modeled consists of a number of smaller processes, a product from the Visual Interactive Modeling Systems category of Table I that uses the Discrete-Event Simulation method is recommended. The reasons for this are:

- Ability to model by steps/events or queues;
- Availability of software;
- Ability to perform "what if" analysis during the simulation run; and
- Ability to subdivide a problem into distinct, manageable problem areas.

Discrete-event simulation software should have the capability of importing CAD drawings into the model as templates. This capability provides users with an added degree of flexibility for using CAD developed drawings as background templates over which a model can be constructed, or as background templates on which objects can be built. The former capability prevents users from having to recreate a drawing within the simulation product environment, while the latter option allows objects to be created and placed within the model being built that closely resemble their actual CAD drawings. These objects could represent stationary background objects or a specific type of vehicle within the model.

There are currently a number of software simulation products available on the commercial market that fall under the Visual Interactive Modeling Systems category identified in Table I. All of these products are 'canned' simulation packages in that they provide pre-constructed elements with which to construct the process model. The simulation models are themselves created by simply selecting the desired element, placing it at the appropriate modeling environment location, identifying the characteristics associated with it, and then linking it to the other elements of the model to show the process dependencies. The amount of programming actually required is dependent on the level of complexity desired in the model.

In selecting a product one should also consider the following factors in addition to the basic features of the product and those factors mentioned above:

- A user interface that provides the best format for ease of adding detail to a model after its initial construction;
- A user interface simulation language that is easy to understand;
- Software capability to develop and use sub-routines in the simulation code;
- Software that provides excellent graphical features, including true 3-D graphics, and the ability to create movies of the process being simulated for viewing on video cassette recording machines;
- Software that provides the ability to construct the model to scale in either U.S. customary or metric units;
- The availability of the software for both PCs and UNIX workstations; and
- The ability to model material flow processes, apply routing logic to the model, assign attributes to model elements, and apply statistical distributions to the processes being modeled.

Some examples of past process flow simulation applications are identified in Table III. These examples were taken from a wide variety of sources that include product information brochures and publications by the American Society of Naval Engineers.

PROCESS FLOW SIMULATION

Due to the ever increasing complexity of the ship design process, where the overall goal is to meet the owner's requirements while designing for affordability, the need for a tool that has the capability of analyzing and determining the characteristics of discrete event shipboard activities has emerged. In an effort to demonstrate the utility of process flow simulation software in fulfilling this need, a small pilot program was initiated that modeled the processes associated with personnel flow through a ship's mess line.

The mess line flow effort was approached in two phases. The first phase included the identification of the mess line process flow interactions that were to be studied, and the collection and development of data to represent these processes. The second phase involved the actual development and analysis of the process flow simulation model.

Process Flow Simulation Applications
Simulation and analysis of the LPD 17 starboard mess line flow
Evaluation of proposed Singapore Port changes/expansions
Use of simulation to create a tool for standardizing the layout of future Taco Bell restaurants
Use of simulation to improve the traffic flow through current Taco Bell restaurants
Simulation of the production processes of the Boeing 777
Simulation of the roll out celebration for the Boeing 777
Simulation of a steel stockyard operation in connection with a lay-out development
Simulation of a cutting shop in connection with the modernization program
Simulation of the entire prefabrication facilities at a Norwegian shipyard
Simulation of different ship construction approaches at a German shipyard
Simulation of different steel fabrication lines for various customers
Motorola and its partners simulated the entire supply chain for the manufacturing and delivery of the low earth orbit satellite communication system
Simulation of the John Hopkins hospital's main cafeteria serving process to both staff and visitors
Simulation of the LHA 1 Class cargo handling system

Table III. Process Flow Simulation Applications

The results that would be obtained from this model would provide the following information:

- The amount of time needed to feed the total crew and troop complement;
- The flow rate of personnel passing through the serving line;
- The number of personnel passing through the serving line in the first 21 minutes (21 minutes represents the allotted eating duration);
- The utilization factors of the Food Service Attendants (FSAs) and Mess Specialists (MSs) along the serving line, and of the FSA restocking utensils; and
- The effects of different mess deck seating variations on the time needed to serve the crew and troops.

As part of the investigation undertaken in Phase I, commercial kitchen standards were utilized, as well as input from Navy supply representatives. This information was used to select a menu to model, as well as to help identify the serving sizes, equipment capacities, process times, and personnel interactions associated with the utilization of the mess line. Another Phase I decision item was the extent to which the galley mess line area would be modeled. Because the task was a small pilot program, it was decided that an application of limited scope would be enough to demonstrate the utility of using a process flow simulation tool in helping to design and analyze food service operations. As a result, the actual scope of the process flow simulation model was reduced to modeling only the starboard serving line, half the ship's personnel, and half the seating capacity. In addition to the ship's personnel utilizing the serving line, the mess line support personnel were also modeled since they have a direct effect on the proper operation of the serving line. Other features that have been incorporated into the model include:

- The traffic flow of the crew and troops during meal time;
- The menu being served and the menu selection distribution of the crew and troops;
- The actions of the crew members in the serving line and of the personnel supporting the serving line, but not those in the galley; and
- The movement of the crew and troops to either of the two entrances into the Mess Deck.

The following sub-section provides a detailed description of the assumptions and methods used in creating the simulation model. The results that were obtained from this model are discussed in the sub-section titled **Simulation Run Results**.

Assumptions and Constraints

In addition to the top level model behavior decisions already mentioned, a number of assumptions and decisions were made with regards to the technical accuracy of the simulation prior to developing the model. These covered such areas as the menu being modeled, food item locations, serving line processing stations, resources required for serving the meal, the characteristics of these resources, and personnel characteristics. The following subsections identify and document these decisions, and provide the reasoning behind them.

Serving Line Layout. The starboard mess line was modeled based on a CAD2 drawing provided to the project team. This drawing served as the template on which the simulation model is built. As a result the simulation model was created to scale with the 3-D elements displayed located above the actual footprints of the objects they represented.

Crew Size. The crew consisted of both the ship's enlisted crew (429) as well as the maximum number of embarked troops (597) that the ship was designed for. With only the starboard mess line modeled in the simulation, the number to be served by this mess line is 513, or half of the total complement.

Mess Deck Capacity. The mess deck was also modeled as half of that identified in the ship's drawings. As a result the baseline simulation model contains only 84 seats.

Mess Specialist and Food Service Attendant Stations and Duties. The mess line support personnel for which utilization rates were determined are identified in Table IV along with their primary duties and location.

Crew Member Identification	Primary Duties	Primary Location
FSA#1	Hotwell Server	Galley behind hotwells 2, 3, 4
FSA#2	Hotwell Server	Galley behind hotwells 5, 6, 7
FSA#3	Hotwell Bin Reloader	Galley
FSA#4	Utensil Bin Reloader	Scullery
MS#1	Grill Operator	Galley behind grill
MS#2	Grill Operator	Galley behind grill

Table IV. Serving Line Manning Requirements

Since the grill is used only to cook chicken breasts for dispensing from the hotwell, only one cook is required for use during the simulation run. As a result MS#1 is not utilized during this study.

Traffic Flow. An equally important element of the simulation model is the traffic flow of the troops and crew members in the serving line, as well as the interaction between them and the crew members on duty in the mess area. To account for these actions a number of assumptions were made. Because one of the basic goals of this project was to determine the throughput of the mess line, it was decided early on that the simulation model would not take into account the staggered arrival process of personnel for meals as would actually occur aboard ship. Specifically, early meal for watch reliefs, head of the line privileges for first class, and late arrival of off-coming watch standers were not modeled. The model also assumed a steady flow of personnel from the starting point after the simulation run began for a worst case scenario. The starting point is the starboard vestibule forward of the bulkhead at frame 47½, which contains the starboard ladder well. These assumptions, in addition to providing an easy method for determining the throughput of the mess line, and the steady flow rate, also helped to simplify the complexity of the model for this pilot study.

In order to accommodate the interaction of the model elements during any given simulation run, a number of other assumptions regarding the traffic flow were also made. These assumptions and the factors that are applied in the simulation model are identified below.

- Width of 95 percentile man = 0.56 m (1.8 ft). [3]
- Personnel walking speed = 1.16 m/sec (3.81 ft/sec). [3]
- Minimum spacing of personnel in the mess line = 0.8 m (2.7 ft) (distance from leading edge of one person to the leading edge of the next).
- Mess line path width = 0.6 m (2 ft).
- Personnel will stay in the mess line until entering the mess deck.
- 60% of the crew will use the starboard mess deck entrance, and 40% will use the centerline entrance
- Maximum capacity in the mess deck = 84 personnel
- Each troop or crew member will use the mess deck for approximately 21 minutes (currently set at constant value).
- The starboard serving line began at the starboard water tight door at frame 47½ from the inclined ladder vestibule and proceed aft.
- The line, as it moves aft, is routed along the outboard bulkhead until frame 60 where it then turns inboard and forward to pass along the serving line.
- If the scullery FSA is reloading a utensil dispenser, then the crew in the mess line will not be able to select that type of utensil until the FSA is finished reloading the dispenser
- The hotwell server assists the hotwell reloader for 12 seconds when one of his or her hotwells is being reloaded; the first hotwell server also assists the reloader with the soup hotwell.
- When the hotwell server is assisting the hotwell reloader, the mess line is unable to select food from that station until the hotwell server is done.
- A Mess Deck Master At Arms will be positioned at the end of the serving line to control access to the mess deck.

The reason the crew member width was based on the width of the 95 percentile man is because it provides an accepted figure that represents the higher end of the range that could possibly be experienced aboard ship. Except for helping to identify the required width of the mess line traffic path, this figure has no other impact on the simulation model or its results.

The mess line flow path was modeled in accordance with the drawings, and as indicated above. In addition, fourteen process or action stations were placed along its length. These stations identify locations where actions are performed by the crew member traveling along the path. As an example, at Station 2, the menu board, each crew member pauses to read the menu. The length of the pause is based on a triangular distribution between 0 and 5 seconds with the mode at 2 seconds. A description of each station is provided in Table V.

Station	Description	Station	Description
1	Mess Line Entrance	8	Hotwell 1
2	Menu Board	9	Hotwell 2, 3, 4
3	Tray Pick Up Point	10	Hotwell 5, 6, 7
4	Plate Pick Up Point	11	Dessert Pick Up Point
5	(For future use)	12	Bread Pick Up Point
6	(For future use)	13	Starboard Mess Deck Entrance
7	Bowl Pick Up Point	14	Centerline Mess Deck Entrance

Table V. Mess Line Routing Sequence

As indicated in Table V, the trays, plates, and bowls were picked up by the person as he or she passed the appropriate station. Crew members were not expected to pick up utensils unless they used it later for the food they were selecting. In other words, unless the crew member wanted soup, or their vegetables in a bowl, they did not pick up a bowl when they reached Station 7. If they wanted both, they selected two bowls.

Only three other items, in addition to the utensils, were modeled as being self served by the personnel as they passed through the line. These items were the soup, dessert, and bread menu items.

The FSA associated with the scullery work was modeled as following a path that primarily consisted of a straight route from the scullery out the centerline entrance of the mess deck, and then down the starboard passageway to the tray dispensers and into the galley. This path was used whenever the FSA was required to restock the trays, dishes, or bowls in the starboard serving line, and also for the return trip to the scullery. It was assumed that both the scullery FSA and the crew members in the mess line avoided each other as they passed, so there were not any delays in the process flow of either entity being modeled due to congestion.

Menu. A dinner menu representative of an actual dinner that might be served aboard ship was chosen for simulation. This menu was selected from the NAVSUP Pub. 421, Food Service Operations, January 1994 [4], and is identified in Table VI along with the specific hotwell or other designated area of the serving line from which the indicated menu item is served. Note: The extended serving line is not modeled and therefore the salad and beverage area are not included in the logics or graphical representation of the starboard serving line.

Location	Menu Item
Hotwell 1	Pepper Pot Soup
Hotwell 2	Grilled Chicken Fillet
Hotwell 3	Tomato Meat Loaf
Forward Half Hotwell 4	Chicken Gravy
Rear Half Hotwell 4	Tomato Sauce
Hotwell 5	Au Gratin Potatoes
Hotwell 6	Steamed Rice
Forward Half Hotwell 7	Seasoned Mixed Vegetables
Rear Half Hotwell 7	Steamed Zucchini
Cold Food Counter	Fruit & Dessert Bar
Cold Food Counter	Hot Pan Rolls
Extended Serving Line	Garden Vegetable Salad

Table VI. Menu Item Locations

Food Selection. In addition to selecting the menu that would be modeled, it was also determined that an appropriate distribution would need to be developed that would reflect the food selection distribution of the troops and crew. The meal selection distribution follows:

- 40% Soup
- 45% Chicken
- 45% Meat Loaf
- 40% Au Gratin Potatoes
- 40% Rice
- 40% Seasoned Mixed Vegetables
- 40% Steamed Zucchini
- 50% Dessert
- 50% Bread

As a result of this distribution 10% of the crew will not select either entree, 20% of the crew will not select either starch item, and 20% of the crew will not select either vegetable item. This distribution also allows for a 0.4 % chance that a crew member will not select an entree, starch, nor a vegetable; if this occurs soup and bread will be selected as default.

Serving Size. The next step in the development of the model consisted of determining the serving size for each item and the maximum amount of servings that would be present in the serving area (in most cases the hotwell).

The maximum number of servings that were allowed in the simulation were dependent on the type of serving container being used. Except for the dessert and bread items, all items were modeled as being served from a hotwell. The model included two different types of hotwell pan. The nominal size and fluid ounce capacities of these two types were identified in the book titled *Commercial Kitchens* [5], and are: 12” x 20” x 2 1/2” for 240 oz capacity, and 12” x 20” x 4” for 464 oz capacity.

The serving capacity of each hotwell was dependent not only on the size of the individual hotwell, but also on the menu item being served from it. The serving size of the menu item, the hotwell pan size it was in, and the maximum number of servings contained by the hotwell is identified in Table VII for each item.

Menu Item	Serving Size	Hotwell Capacity (oz)	Servings/ Hotwell
Pepper Pot Soup	8 oz	464	58 servings
Grilled Chicken Fillet	15.25 sq in	240 or 240 sq in area	15 pieces/layer or 48 servings
Tomato Meat Loaf	5 oz	240	48 servings
Chicken Gravy	2 oz	232	116 servings
Tomato Sauce	2 oz	232	116 servings
Au Gratin Potatoes	6 oz	464	77 servings
Steamed Rice	3 oz	464	154 servings
Seasoned Mixed Vegetables	5 oz	240	48 servings
Steamed Zucchini	5 oz	240	48 servings
Fruit & Dessert Bar	N/A	N/A	N/A
Hot Pan Rolls	N/A	N/A	N/A
Garden Vegetable Salad	N/A	N/A	N/A

Table VII. Menu Item Serving Size and Hotwell Capacity

For the pilot program, the fruit, dessert, and hot rolls were modeled as being unlimited in quantity, and therefore did not require tracking or restocking. The salad bar is not included because it was decided at the onset of this project that the salad bar would be located in the mess deck, and that the mess deck would not be modeled in any detail.

In working these elements into the logic of the simulation model, it was assumed that, except for the soup, all hotwell items would be served by one of the two FSAs behind the hotwell serving area. It was also determined that at various times throughout the simulation any one of these hotwells might require restocking. This can be verified by simply comparing the hotwell serving sizes indicated in Table VII to the crew and troop size being modeled (i.e. half the ship’s crew and troop complement, or approximately 513 crew members). As a result, a hotwell restocking process was incorporated into the model. This restocking process involves a FSA working in the galley, and requires him or her to manually replace the hotwell.

The actual restocking process is initiated when the quantity contained within a hotwell reaches a specific level. For this model it was determined that this level would be at 10% of the initial quantity. This assumption is in close accordance with the process that actually occurs aboard ship, where the pans are usually never completely empty before a replacement pan is placed in the serving line. It was also decided that any left over servings from the old pan would be added to the amount contained in the new pan when the restocking process occurred.

In addition to these assumptions, it was also decided that the initial amount in an original or replacement hotwell would be either 90% or 75% of the maximum capacity depending on the type of item in the hotwell. For liquids 75% was used, while 90% was used for solids. This margin in hotwell capacity was intended to: prevent items from falling or sloshing out of the hotwell pan as it or the ship moved; and prevent spills from occurring due to the addition of the leftovers to the hotwell replacement pan.

The serving amounts identified in Table VII were therefore adjusted. It was also decided that the replacement amount for a hotwell would be equal to its initial amount of servings. Although these factors are identical, in the simulation model's code they are independent variables and may be changed by the user when desired.

Utensil. The utensil dispensers modeled in this simulation are based on the selected ship design drawing obtained by the project team. In that design drawing it was identified that the tray, plate, and bowl dispensers would be located along the mess line, and the silverware would be obtained from above the tray dispensers. It was also specified that the trays would be of the non-segmented or flat type, and that the silverware would be obtained when a tray was. Because of this the silverware and trays are modeled and tracked as one unit.

In working these elements into the logic of the simulation model, it was also assumed that 40% of the crew would want to use a bowl for something other than soup. In this model this other use was to hold vegetables. Another area of concern that was addressed by the model was the restocking of these utensil dispensers. Since none of the dispensers have an initial quantity large enough to support the troop and crew size being modeled the restocking process for the dispensers was also incorporated into the model. This restocking process involves a FSA working in the scullery, and requires him or her to manually carry the restock load from the scullery to the appropriate dispenser. Mobile carts cannot be used because the scullery has a 22.9 cm (9 in) sill around it to prevent water from entering the mess area.

The actual restocking process is initiated when the quantity contained within a dispenser reaches a specific level. This level along with the initial amount and refill size for each dispenser are identified in Table VIII. Note: Refill size indicates load size carried by the scullery FSA.

Utensil Name	Initial Amount	Refill Point	Refill Size
Tray Dispenser 1	150	50	25
Tray Dispenser 2	150	50	25
Plate Dispenser 1	72	24	12
Plate Dispenser 2	72	24	12
Bowl Dispenser 1	36	12	12
Bowl Dispenser 2	36	12	12
Bowl Dispenser 3	36	12	12

Table VIII. Utensil Dispenser Refill Information

Once the restocking process is initiated for a utensil dispenser, the scullery FSA will make as many trips as required in order to bring the utensil dispenser's amount equal to, or above, its refill point.

Process Time Assumptions. In order to create a simulation model that reflected the actual mess line process as accurately as possible, process times were required to be associated with each specific process being modeled in the simulation. Because of the inherent variability of the time associated with any of these processes, distributions were also attached to some of them in an attempt to more accurately reflect what would occur as the process is repeated throughout the duration of the simulation. Unfortunately, due to the inability to conduct time studies on which to base these distributions, few of the process time durations used are statistically based. As a result assumptions were made regarding the time required for crew members to perform their duties and conduct the modeled tasks. The times associated with the FSAs and MSs performing their tasks are identified in Table IX. The soup, dessert, and bread are self served, and MS#1 is not modeled.

Serving Time (FSA#1 & FSA#2)	**Hotwell Bin Refill Time (FSA#3)**
Chicken = 5 sec	Hotwell Reload Time = 30 sec
Meat Loaf = 5 sec	**Utensil Bin Refill Time (FSA#4)**
Chicken Gravy = 5 sec	Scullery load pick up time = 5 sec
Tomato Sauce = 5 sec	Scullery load drop off time = 5 sec
Au Gratin Potato = 5 sec	**Chicken Prep Time (MS#2)**
Rice = 5 sec	Grill time = uniform 10 ± 1 min
Seasoned Mixed Vegetables = 5 sec	for 43 chicken breasts
Steamed Zucchini = 5 sec	Placement in hotwell = uniform
Hotwell Reload Assist Time = 12 sec	5.75 ± 1 min for 43 chicken breasts

Table IX. Resource Utilization Times

The processes for which time lengths are associated with the personnel transiting the serving line are identified below.

- Menu read: triangular distribution 0, 2, 5 seconds.
- Tray pickup: constant distribution 2 seconds.
- Plate pickup: constant distribution 2 seconds.
- Bowl pickup: constant distribution 2 seconds.
- Desert pickup: constant distribution 2 seconds.
- Bread pickup: constant distribution 4 seconds.
- Mess deck use: constant distribution 21 minutes.

The mess deck utilization of 21 minutes is based on the standard design factor of 18 minutes of use per person with an additional 3 minutes to account for the time taken to get his or her drink and salad, find a seat, and clear the area after finishing eating.

Graphics

In addition to creating the logic for the simulation model, 3-D graphical images were also created so that the actual process flow of the starboard mess line could be visualized. These graphical images, created within the simulation software product AutoMod, display the changing status of the model during the simulation run. The frequency at which these graphical images are updated can be specified by the user, but by default is every 1 second of simulated time. These 3-D images represent the bulkheads and equipment that are pertinent to the portion of the serving line mess area being simulated. The equipment is approximately equal to its real life size, and is positioned as indicated on the CAD2 drawing. The primary use of the visualization capabilities of these types of simulation projects is to visually verify the accuracy of the process being modeled, and to visually convey the process being simulated to someone unfamiliar with it. Sample screen prints of these images are shown in Figures 1 and 2.

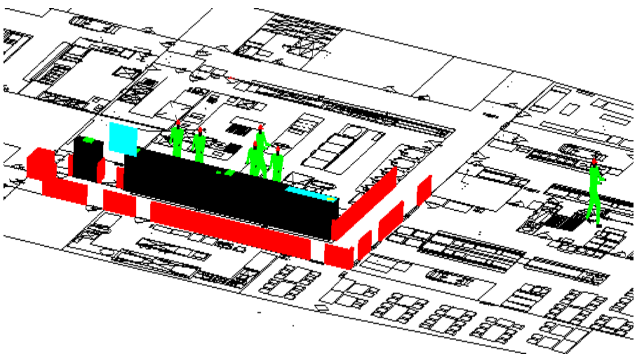

Figure 1. Serving Line Overlaid On CAD Drawing

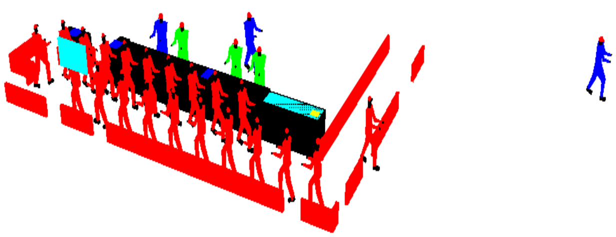

Figure 2. Starboard Serving Line In Use

Simulation Run Results

Prior to discussing the results of the simulation analysis of the selected ship's starboard mess line it should be emphasized that the results obtained are based on the assumptions and conditions modeled. Although these assumptions and conditions were judged to be reasonable they were not validated. Therefore until validated data is obtained, the results and conclusions drawn from this analysis are only applicable to this model.

Using the simulation software, the ship's starboard crew mess line was modeled in accordance with the information and assumptions presented in this paper. Due to the deterministic nature of these assumptions (i.e. all but two time delays were constant numbers), only one simulation run was performed for data collection. The primary reason for this is that deterministic models show no variance between individual runs; the event sequencing, lengths, and interactions are by definition predetermined. Except for the mess cook grilling the chicken to refill the chicken hotwell, and each crew member pausing at the menu board in order to read it, the model developed for the ship's starboard crew mess line was deterministic. This classification was quantified during the model testing stage when a number of runs, utilizing various starting points on the random number stream, as well as a different type of random number stream, were made and analyzed. The results of each test run were identical, i.e., the overall time length for serving the crew and troops did not change between runs.

The primary reason for the deterministic nature of the assumptions used in this model is due to the unavailability of data on which to accurately base and select the form of the statistical distributions. Modifications however, can be made to the model when this data becomes available, thereby implementing the statistical distributions and obtaining a stochastic process.

In addition to simulating the use of the starboard mess line for a half mess deck capacity of 84 seats, eight other simulations of increasing mess deck capacity were also made. Each of these runs was performed under the exact same constraints and conditions as the original run except for the factor identifying the mess deck capacity. This factor was increased in increments of five, until a capacity of 119 seats was reached, and then set at infinite. The overall objective of this analysis was to determine the effect of increasing the number of seats in the mess deck on the crew feeding time, as well as the utilization rates of the personnel supporting the mess line. The final run at infinite seating capacity was performed in order to evaluate the true efficiency of the serving line without any seating constraints being imposed upon it. Specifically the mess deck wait delay constraint, symbolizing the Mess Deck Master At Arms control of the mess deck access when all mess deck seats are occupied, was negated.

Simulation Run Time. The total serving and messing time associated with each run is identified in Table X, along with the maximum duration spent waiting by any one crew member during the messing process. The total serving and messing time represents the amount of time required for all 513 troop and crew members to process through the starboard serving line and eat their meals in the mess deck. The mess deck wait process symbolizes the interaction and effect of the Mess Deck Master At Arms on the mess line flow as he or she controls access to the mess deck when all seats are occupied. The maximum mess deck wait duration times displayed in Table X identify the longest time spent by any one crew member waiting to enter the mess deck. The specific crew member that had to wait is identified by Crew ID Number. The Crew ID Number represents the identity of the troop or crew member being processed through the simulation, i.e. Crew ID Number 1 represents the first person in line, while Crew ID Number 215 represents the 215th person in line. Note: The times in Table X have been rounded off to the nearest second.

Half Mess Deck Capacity	Process Information: Total Serving and Messing Time (hrs:min:sec)	Maximum Mess Deck Wait Duration (min:sec)	Crew ID #
84	2:31:37	6:18	85
89	2:28:44	5:26	90
94	2:27:43	4:25	95
99	2:26:41	3:40	100
104	2:25:53	2:36	105
109	2:25:20	1:43	110
114	2:23:36	0:52	115
119	2:24:11	0:05	145
Infinite	2:24:11	0:00	N/A

Table X. Process Information

As can be seen by examining Table X, and as would be expected, the influence of the mess deck seating on the overall mess line performance decreases as the seating capacity of the mess deck increases. In fact at 119 seats the maximum mess deck wait delay experienced by any crew member is only five seconds, a negligible amount.

A similar conclusion might also be drawn from examining the Total Serving and Messing Times, presented in Table X, for the nine conditions modeled. But as can be seen in Table X, the process flow time decay rate does not produce a smooth transition between runs as might be expected. The dip in the decay rate, shown for a half mess deck seating capacity of 114 seats, indicates that the interaction between the mess deck seating capacity and the processes occurring in the serving line is the most efficient at a half mess deck seating capacity of 114 seats.

Serving Line Throughput. Another goal of this project was to determine the number of personnel passing through the serving line (i.e. completing all processes through station number 12) in the first twenty-one minutes. This time span, which equals the time spent by a troop or crew member using the mess deck, was examined in order to obtain a throughput that was reflective of the serving line and its inherent characteristics, and not of the serving line plus the constraints imposed upon it by the seating capacity of the mess deck. The results are identified in Table XI.

Half Mess Deck Capacity	Number Served
84	85
89	90
94	95
99	100
104	105
109	110
114	114
119	114
Infinite	114

Table XI. Number Of Personnel Served In The First 21 Minutes

As can be seen by examining Table XI, the maximum serving line throughput for the first twenty-one minutes of simulation run time is 114 crew members. Before identifying exactly when this point is reached though, some explanation of the data presented needs to be made. The serving line throughput, as shown in Table XI, is one person greater than the mess deck capacity for capacities of 109 people and below. The reason for this is that the delay imposed by the Mess Deck Master At Arms when the mess deck is full is imposed immediately after a crew member has passed through the serving line (i.e. finished processing through station number 12). As a result, although crew member number 85, using a mess deck capacity of 84 as an example, passes through the serving line in under twenty-one minutes, he or she has to wait for a certain amount of time prior to proceeding into the mess deck. As previously mentioned this wait signifies the amount of time required before a seat opens for him or her to use. Because this wait is imposed in the physical location of the last station (a location where a food service process occurs), the serving line throughput halts until this person is able to proceed into the mess deck. Using this as the basis of the interaction that is occurring in the simulation model at the end of the serving line, it can be deduced that the serving line throughput reaches a maximum at a mess deck seating capacity of 113 seats.

Support Personnel Utilization. Identification of the utilization rate for the mess line support personnel was another important goal of this project. The determination of the utilization rates not only helps to better understand the interactions being simulated, but also provides information related to manning reduction opportunities. The utilization rates of all of the support personnel used in this model are identified in Table XII. The location and duties of these support personnel are defined in Table IV. It should also be mentioned that in Table XII, the resource utilization factor has been rounded off to the nearest tenth of a percent and is determined by the following equation:

$$\text{utilization} = \frac{\text{total claims * average time per claim}}{\text{total clock time}} \quad [6]$$

	Half Mess Deck Capacity								
	84	**89**	**94**	**99**	**104**	**109**	**114**	**119**	**Infinite**
FSA#1	51.2	52.2	52.6	52.9	53.2	53.4	54.1	53.8	53.8
FSA#2	46.5	47.4	47.7	48.1	48.3	48.5	49.1	48.9	48.9
FSA#3	11.2	11.4	11.5	11.5	11.6	11.6	11.8	11.7	11.7
FSA#4	50.7	52.3	53.3	53.6	53.4	53.6	54.3	53.3	53.3
MS#2	33.8	33.6	33.9	34.4	34.0	35.6	35.0	35.0	35.0

Table XII. Resource Utilization Rates In Percent

Except for an occasional small deviation, the support personnel utilization rates presented in Table XII behaved as expected, increasing as the mess deck capacity, and therefore serving line throughput, increased, and the overall process flow or simulation run time decreased. It should also be noted that the highest utilization rate for the FSA support personnel occurred at a mess deck seating capacity of 114 seats. This is as expected since, as previously discussed, the interaction between all of the processes being modeled in the simulation was the most efficient under this mess deck seating condition.

Mess Line Simulation Conclusions

Based on the results of the simulation runs many conclusions can be drawn on the modeled galley mess line design. The first is that increasing the number of seats has a minimal effect on reducing the overall serving and messing time. Secondly, the mess deck seating capacity does have a large effect on the mess deck wait time imposed by the mess deck master at arms when all mess deck seats are occupied. These conclusions are supported by the data shown in Table X.

Other conclusions (based on the assumptions used) that can be drawn to demonstrate the utility of the model include:

- The length of time required to serve and feed the entire crew and troop complement with both the port and starboard serving lines is approximately:
  - 2 hours and 32 minutes for the baseline design mess deck capacity of 168 seats
  - 2 hours and 24 minutes for a mess deck with infinite seating capacity
- The combined overall average serving line flow rate based on serving the entire complement of crew and troops using both serving lines is:
  - 8.0 people per minute for the baseline design mess deck capacity of 168 seats
  - 8.4 people per minute for a mess deck with infinite seating capacity
- The number of people that can be served in the first twenty-one minutes from both serving lines is:
  - 170 people for the baseline design mess deck capacity of 168 seats
  - 228 people for a mess deck with infinite seating capacity
- At an 11 to 12 percent utilization rate, the FSA responsible for hotwell restocking is a good candidate for manning reduction assuming no additional duties than those modeled are actually assigned to this person.
- At a 50.7 to 53.3 percent utilization rate for one serving line, the scullery FSA is a good candidate for a manning increase assuming that this person is solely responsible for restocking the utensil dispensers in both the starboard and port serving lines.
- The serving and messing time performance curves indicate that the interaction between the serving line and the mess deck is most efficient at a mess deck seating capacity of 228 seats.

The modeled results also indicate that the baseline serving line may be over designed for the actual environment in which it will operate. As identified above, the maximum throughput that can be obtained for the current design, as modeled with a mess deck capacity of 168, is 170 crew and troop members in the first 21 minutes. This raises several questions concerning the serving line design as modeled. These questions include:

- Might less capable and less expensive serving line equipment result in a throughput more commensurate with that imposed by the mess deck seating capacity constraint?
- Can the Mess Deck Master At Arms duties and responsibilities be eliminated if the serving line was designed with a throughput matching that imposed by the mess deck seating capacity constraint, and therefore allowing a constant flow of personnel into the mess deck? This is a possible manning reduction opportunity.

The most important conclusion is that the time required to serve and feed the crew and troops can be significantly reduced only by addressing both the mess deck seating capacity constraint and the serving line design and process interactions together.

It is again emphasized, however, that the results obtained and conclusions mentioned above are based on input data assumptions that were judged to be reasonable. The specific purpose of this pilot program was to demonstrate the utility of process flow simulation tools.

VISUALIZATION TECHNOLOGY

Virtual Ship Production

This portion of the paper summarizes the work performed using visualization technology to simulate the production process of a hypothetical amphibious class ship. To assist in this effort a detailed master construction schedule of the ship was developed using the *LX Preliminary Design (PD) Generic Build Strategy Study* as a reference. The production process was modeled by scheduling the ship's identified blocks through the fabrication, assembly, and erection phases of construction. Linkages from the schedule to the visualization tool were developed to enable the schedule to drive the visualization sequence for the erection phase. Certain long lead material items are also included in the schedule and, therefore, are part of the visualization.

In order to keep the task generic in nature, a series of twelve staging areas are used to queue blocks after completion of assembly and prior to erection. The visualization illustrates the erection process from the staging area forward to final ship completion. The screen templates track the elapsed time in weeks for an easy to gage real time status of the ship construction process. Various other useful templates are available to customize the software.

The results of the task provide a good first step in the evaluation of the early stage design/producibility interface. The visualization methodology used can be developed as a shipyard specific tool to evaluate ship acquisition proposals, and for project management of the acquisition process. Because the methodology used can be customized and expanded upstream into the total construction process, the scheduling/visualization integration capability of the shipyard's various processes is unlimited. Another unique aspect of this task is that the whole process is Personal Computer (PC) based with reasonably priced commercially available software products. This allows the concept to be used without special hardware or major software investment. Also, as an early stage design tool, this process is easily conveyed on a network setup to management, systems engineers, technical leaders, and ship designers. This concept also allows for evaluations early on in the design process and at the early stage of the contract design phase.

The block break configuration was developed by importing CAD files from the ship computer model. Because of this, it is easy to develop and simulate alternate build strategies, and visually evaluate engineering changes and their affects on the producibility of the ship. The data produced will also allow the use of "what if" scenarios to evaluate schedule alternatives and ship construction sequences, and provide the ability to play the actual erection sequence out as a visualization.

Every effort was made in the development process to keep the process as simple as possible and user friendly. Also, an objective was to have the programs run on available hardware configurations without major added cost to the end user.

Software Selection

The software products selected for use in the development of the project's **Virtual Ship Production** product are as follows: Microsoft Access Version 2.0, Microsoft Project Version 4.0, Autodesk 3D Studio Release 4.0, and Microsoft Visual Basic Version 4.0. The criteria used in choosing these products included platform portability, cost, performance, and data exchange capability. Microsoft Visual Basic was selected as the programming language with which the links and interfaces between each of these products were built.

Database Software. The selected software was chosen to support the database requirements of the project because of the product's following four characteristics:

- It has become a leading PC based relational database software.
- It provides a smooth data pipeline between itself and the chosen project scheduling software.
- It has an exceptional report generator.
- It possesses a common programming language with the other software products.

In addition to the above four characteristics, the software was also chosen because it and the project scheduling software have mutual import/export capabilities. This can be done in a native file format as well as several intermediate format styles. The native file capability means that project scheduling software can write directly to the database software and then read back the data into a project file.

The report writer associated with the database software uses the powerful capabilities of query by example, multiple data sources, and a wide range of data formatting and conversion functions. All of this along with cross-tab and free form report formats makes the database report generator a logical choice for this project.

Project Scheduling Software. The project scheduling software was selected as the project management software for the following reasons:

- Affordable to second tier shipyards;
- Pert network capability;
- Common data structure;
- Common programming language; and
- Interfacing/Object linking and embedding (OLE) capability with the other software products.

Visualization Software. The visualization software product for this project was chosen because of the following product capabilities.

- COTS software.
- PC compatibility.
- Capability of providing an animation sequence that could be viewed on the operator's PC.
- 3-Dimensional graphic environment to adequately show ship's block break arrangement and assembly/build strategy sequence.
- Capability of interfacing with scheduling and database management programs in order to accurately represent the positioning and sequence of the identified ship blocks during the "virtual" construction, assembly, and erection phases.
- "Keyframing" programming language that allows easy control of animation by reading, line by line, an ASCII datafile output from another program. Direct input of movement information into the 3-D model environment is thereby performed.
- Command line rendering capability, which allows for easy access and processing from within another user interface, or shell program.
- Single frame, and range of frames, rendering capability which allows the user to quickly render and view any particular moment in the animation sequence without having to render the entire sequence. This saves on rendering time. (Note: Rendering is the process whereby the visualization software creates the graphical image being portrayed.)
- High quality rendering modes include photo-realistic still scene rendering, and variable quality and size rendering. These modes allow for the production of single frame still shots for printing and display, as well as for control over the disk space and rendering time requirements of animations. Flat, Gouraud, Phong, and Metal-shading modes also support any range of image resolution, thereby giving the user control over animation output to allow for any system disk space or time constraint consideration.
- Network rendering options that allow the distribution of rendering tasks to other PCs running this software in order to reduce the overall rendering time of the animation sequence.
- Still images can be saved as color .GIF, .JPG, .TGA, .TIF, .BMP, and .JPG picture file formats that are widely used throughout various PC graphics packages and software applications.

In addition to these factors the product was also chosen because it is a well rounded visualization software package that is used by a broad range of professionals (i.e. videographers, architects, engineers, etc.) and has a large product support base.

Integration Software. The integration software was chosen for this project for the following reasons:

- It is a capable Windows application development environment,

- It can utilize data from many sources in many formats, and
- It can programmatically process data.

With the integration software, the developer can organize and design screen-based forms that present the data of a project in logical and coherent ways. Industry standard controls can be used, such as drop down lists, buttons and menus. In this project, the integration software allowed the developers to display and deal with the **Virtual Ship Production** project data in a highly customized, more efficient way.

The integration software is capable of complete, broad based data manipulation. It can read and write data from numerous sources and it has extensive internal capabilities for formatting and converting data. In this project, the integration software is used as a data intermediary that moves data between applications, displays the data, and processes it for use in an animation program.

The integration software provides a rich, extensible programming language and as such it is used in this project to process the data it can reach. This processing includes converting project data into a sequential list of events, scheduling the list of events to follow a bin filling scheme utilizing variable resources, and generating the data elements to record the event. While processing, the integration program checks for errors, keeps statistics on resource usage, and converts the data format to one that can be used by the animation program. The information is then output to a file that is used as input for the animation.

Product Model Development

Platform Selection. As previously alluded to the goal of this project was to develop a tool that offers the following capabilities/features:

- Uses Simulation Based Design (SBD), and High Performance Visualization (HPV) technology to model ship production breaks and erection sequence.
- Provides the capability of incorporating CAD Library information for machinery and outfit components, and establishes linkages with production schedules such as erection and material ordering schedules.
- Incorporates engineering interfaces which provide a user friendly environment for this effort.

With these overall goals of the project tasking in mind, the basic objectives of the project's product, **Virtual Ship Production**, were further refined. As a result it was determined that the end product should provide the following features and capabilities:

- Presentations for progress reviews.
- Product platform portability (i.e. PC based with COTS software).
- Progress tracking with color presentations for shipyard internal use.
- Process lane resource planning, and throughput/bottleneck identification.
- Internal management presentations for "what if's" at the vice president level and higher.
- Detail tracking of completion at the workstation or gate level with process lane/work station simulations.
- An animated demonstration of the erection sequence for production planners, superintendents and foremen as a training tool.
- Interactivity allowing the user to modify the schedule to reflect problems or changes that occur during the ship construction period and identify the corresponding results that occur.
- A production schedule that links the fabrication, assembly, and erection of the ship's blocks with the ordering, inspection/preparation, and landing of equipment, and other important milestones.
- The ability for the user to evaluate different production schedules and choose the one that best fits his or her requirements (i.e. optimum construction time, finance requirements, work load leveling, etc.).

Master Construction Schedule Development. The development of a detailed master construction schedule was accomplished with the above mentioned features and capabilities of the finished product **Virtual Ship Production** in mind. As mentioned the information contained within the *LX Preliminary Design (PD) Generic Build Strategy Study* was used as a reference. Specific items of interest contained within this study included:

- Block Break Plan
- Key Event Schedule
- Master Construction Schedule
- Hull Erection Schedule
- Typical Long Lead Time (LLT) Schedule
- Typical LLT items
- A preliminary Master Equipment List (MEL)

The Master Construction Schedule created for the project therefore was in a large part based upon the information contained within the *LX Preliminary Design (PD) Generic Build Strategy Study*. The work done in developing the new Master Construction Schedule was initiated on project scheduling software, and later transferred to the database software via the front-end interface developed for this project.

Identification Of Tasks/Events. Many resources were utilized in identifying the tasks or events that would be tracked by the new Master Construction Schedule. In addition to the information contained within the *LX Preliminary Design (PD) Generic Build Strategy Study*, historical ship construction information was used as well as the shipyard experience of some of the project team members was used.

Based on the information culled from these sources it was decided that as a minimum the Master Construction Schedule would be centered around the following production processes, or areas of concern:

- Ship Construction Milestones
- Hull Construction

* Outfitting

These areas of concern, or production processes, can be further broken down into sub-elements as identified in Table XIII.

Milestones	Hull Construction	Outfitting - Equipment
– Contract Award – Detail Design – Start Construction	– Fabrication – Assembly – Erection	– Ordering – Receipt, Inspection, & Preparation – Landing
– Lay Keel – Launch – Builders Trials – Delivery	**Note: The above subdivisions can be further classified by:** – Zone – Sub-Zone – Block	

Table XIII. Minimum Contents Of A Master Construction Schedule

Milestone/Miscellaneous Events. A number of milestones and miscellaneous events are involved in scheduling and managing a ship construction process. Although all of these events should be used in developing a ship's Generic Build Strategy and overall production schedule, only ten of them are identified and visually displayed by the project's associated graphics package. These ten events are identified below:

* Contract Award
* Detail Design
* Start Construction
* Lay Keel
* Start Superstructure Erection
* Launch
* Dock Trials
* Builders Trials
* Acceptance Trials
* Delivery

These events were chosen for the following reasons:

* The nature of the event lends itself to being easily shown during the visualization of the ship production process;
* The scheduling and completion of the event, or task, greatly effects the overall production process;
* The event, or task, can be easily used to gauge the progress of production; and
* There is a distinct start, stop, or time period associated with the task, or event.

Hull Construction. The shipbuilding process currently utilized by modern shipyards is based upon the principle of Group Technology (GT). In addition to being a philosophy of grouping products based on similar production characteristics, GT is also used as an umbrella which covers a number of other production methods. The Hull Block Construction Method (HBCM), used during the structural construction of ships, is one of the methods which falls within the domain of GT. In HBCM, ship structures are incrementally built up from interim products until the final product, a ship's structure, is achieved. Depending upon the design, and the production capabilities of the shipyard, this method of ship construction can employ up to seven different manufacturing levels. These levels are characterized primarily by the stage of production in which they are found, and can also be further classified into three groups based on their predominant production aspects.

For the purposes of this project though, the work flow path was modeled as consisting of the following four basic steps:

* Block Fabrication
* Block Assembly
* Crane Transfer
* Block Erection

There were a number of reasons for this reduction in the detail of the HBCM work flow path, including the fact that it is the Block, and not necessarily the interim products (i.e. semi-block assembly, sub-block assembly, part assembly, and part fabrication), that is the key structural element in the construction of a ship. In other words, the ship's Block Breakdown, and the resultant production aspects of each Block, determine the work flow that will be experienced during the ship's construction process. Other reasons for minimizing the amount of detail concerning the ship construction process that is tracked and visually presented in this project include:

* The Master Construction Schedule contained within the ship's Preliminary Build Strategy identified the structural start and stop events associated only with block fabrication, assembly, and erection.
* Shipyard Master Construction Schedules normally track only the following structural events: block erection, block assembly, and block fabrication. (Note: Sometimes these latter two events are tracked as a single event.)
* The three events tracked are directly germane to the erection of the ship

The crane transfer task has been added to the revised HBCM work flow path in order to represent the transfer by crane of the blocks from the staging area to the erection site.

For this project the hypothetical ship's hull construction process is modeled as consisting of 184 blocks. Each of these blocks will be individually identified and tracked by the project's product model.

Outfitting. The outfitting process in ship production is an extremely complicated one that can also, if not properly managed, be very time extensive. Like HBCM, there is also an outfitting method specifically associated with Group Technology. This method, called the Zone Outfitting Method (ZOFM), incorporates the same principals and philosophies of Group Technology that HBCM does. In ZOFM, the outfitting process is broken down into a sequence of steps that indicate the process taken in landing equipment aboard ship. There are six different stages, or manufacturing levels associated with the Zone Outfitting Method.

As with HBCM, the outfitting process being modeled in this project is an abbreviated form of ZOFM. Unlike the original process, which contains six different manufacturing levels, the revised outfitting method only identifies three manufacturing levels. These levels are identified in Table XIV, and are meant to only identify the major process associated with placing equipment onboard the ship and not describe the entire process in detail. This reduction in the amount of detail being represented was done in order to develop a management tool that contains a similar level of detail to that normally associated with the upper management level in a ship construction program.

Outfitting Level - Equipment	Description
Ordering	Point of time at which the item is ordered.
Receipt, Inspection, and Preparation (RIP)	Span of time covering the processes associated with the item's receipt, inspection, and preparation for landing in the block or ship.
Landing	Process of actually placing the item in the block or ship.

Table XIV. Outfitting Manufacturing Levels Modeled

For the purposes of this project, it was decided to model only the outfitting process associated with some of the ship's critical equipment and/or long lead time (LLT) items. The selected items, and the blocks with which they are associated are identified in Table XV.

The relationship that the critical equipment/LLT items being modeled in this project have with the phase of ship construction in which they are landed is identified in Table XV. In this table the *After Block Erection* phrase signifies on-board outfitting, and indicates that the landing of the item can not occur until after the erection of the block in which it will be placed has been completed. Likewise, the phrase *During Block Assembly* indicates that the item will be landed or joined with the block during the block's assembly phase; it represents on-block outfitting. Not shown in this Table, and therefore not tracked by the project model, are the first two stages of assembly as identified by ZOFM. Theses stages, *On Unit Outfitting or Unit Assembly* and *Grand Unit or Grand-Unit Joining*, are associated with the process of joining a component to another component which will eventually be landed either in a block or on-board the ship. An example of this is a controller for a fire pump module; it is joined, with some other equipment, to a firepump, but not directly to the block or the ship. It is the module that is actually joined, and therefore it is the module and its associated manufacturing processes that are tracked by a ship construction program's upper management.

Equipment	Associated Block	Ship Construction Landing Phase
Main Engine	3102	After Block Erection
Reduction Gear	3102	After Block Erection
Main Engine	3402	After Block Erection
Reduction Gear	3402	After Block Erection
SSDG	2201	After Block Erection
SSDG	2202	After Block Erection
SSDG	3202	After Block Erection
SSDG	3501	After Block Erection
SSDG	3502	After Block Erection
Switch Board	2221	After Block Erection
Switch Board	2222	After Block Erection
(2) Switch Boards	3221	After Block Erection
Switch Board	3521	After Block Erection
Switch Board	3522	After Block Erection
Steering Gear	4421	During Block Assembly
Steering Gear	4422	During Block Assembly

Table XV. Equipment Landing and Associated Ship Manufacturing Level

Identification Of Event Interdependencies Or Linkages. In addition to identifying the events that will be tracked, the dependencies or linkages between them also need to be identified in order to develop a model that accurately portrays the shipbuilding process. These dependencies and linkages cover a wide range of focus that includes both the general sequencing of the events, and the delays inherent in progressing from one event to the next.

For this project, the linkages between each event were modeled as closely as possible to the actual linkages that occur in a shipyard. A simple example of this is some of the dependencies that were developed for the outfitting process. As already mentioned, the outfitting process is represented in the project's product**, Virtual Ship Production**, as three simple and basic events: Equipment Ordering, Equipment RIP, and Equipment Landing. The dependencies that were developed to help realistically portray this sequence are listed below.

- Equipment ordering occurs prior to equipment RIP.
- Equipment RIP occurs prior to equipment landing.
- Equipment landing can not occur until after the appropriate block is ready to receive it (i.e. depending on the equipment either after block erection or during block assembly).
- There is a one day delay imposed prior to the start of the next sequential event (i.e. if RIP for a specific equipment concludes on Monday, the landing of that equipment can not start until Tuesday).
- The baseline timespan between ordering equipment and receiving is commensurate with the procurement lead time required for ordering that equipment.
- A crane is required to be available in order to transport the equipment from the equipment staging area to the area in which it will be landed.

- Construction of the block is not completed until all components are installed.
- If the equipment is to be installed on board then it will be landed prior to the block's covering (i.e. through open air).

Similar dependencies were also created and imposed on the ship's structural construction processes as identified by the project's product model, **Virtual Ship Production** (i.e. Block Fabrication, Block Assembly, and Block Erection).

In addition to these dependencies, inter-block dependencies, or linkages, were also developed for the erection sequence in order to ensure that any proposed Hull Erection Schedule accurately portrayed and incorporated the sequencing prerequisites that shipyards are subjected to. These inter-block dependencies are identified in the following list, and are applicable to the majority of blocks associated with a ship.

- Erect from the mid-body area outwards.
- Inner blocks are erected prior to wing wall blocks.
- Blocks are not covered until all appropriate equipment that needs to be joined to them at the erection site are landed (for this project see Table XVI).
- Erection of a block on top of another requires that the lower block, and adjacent lower blocks within the same 'Unit' are already erected.
- Sufficient time is provided for the fitting and welding of blocks prior to landing new blocks over them.

In short, the above mentioned dependencies are rules that in most cases closely resemble the 'rules of thumb' utilized by shipyard planners. How close these 'rules of thumb' are adhered to is dependent on the specific design aspects of the ship being erected. For this project, these rules form the cornerstone around which any proposed erection schedule will be built. As such, they have been entered, where applicable, as predecessors to each event in the ship's production schedule, and should not be over-ridden except by the program manager, or his or her representative, in order to ensure model integrity.

Software Product Interface

The next few subsections describe the user interface of the **Virtual Ship Production** product, and some of the interface's special features. These special features include the ability to apply cost figures to the tasks being tracked, as well as being able to apply both the Ship Work Breakdown Structure (SWBS) and Product Work Breakdown Structure (PWBS) classification system to them.

Data Entry Templates. The main, or first, template of the **Virtual Ship Production** product is shown in Figure 3. The discussion and screen prints that follow this figure describe the user interface, or templates, of the product **Virtual Ship Production**.

Clicking on the Data Tool button, Figure 4, will bring up the Virtual Data form. This form is used to view and edit data that is specific to the ship building schedule. The data that is available on the Virtual Data form is more detailed than that which is generally available in the project schedule file. Any schedule data that is edited on this form is transferred back to the project schedule file thereby changing it. Any non-schedule data that is added or edited will also be stored with the project schedule file.

The Virtual Data form, Figure 5, is comprised of two main areas. The filter area allows the user to narrow the scope of task events that can be viewed. The tabbed folder displays the actual project data.

The filter area has three option buttons and a drop down list. The option buttons determine what type of task events to show in the drop down list. One can

Figure 3. Virtual Ship Production Master Template

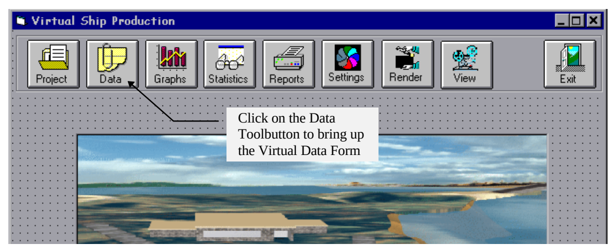

Figure 4. VSP Data Tool Button

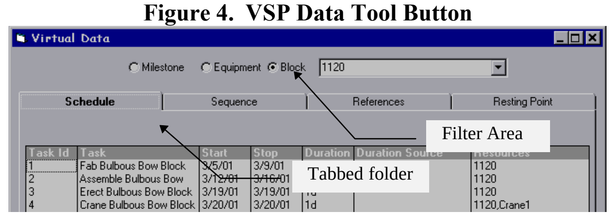

Figure 5. VSP Virtual Data Form

select either milestone, equipment, or block tasks to be listed on the drop down list. From the drop down list a particular item can be picked and the data viewed on the tab folder.

The tabbed folder has four tabs across the top that break out the details of the project data. These tabs are titled Schedule, Sequence, References, and Resting Point.

The Schedule tab, Figure 6, contains a table grid that displays some of the basic data items from the project. The table grid is divided into seven columns. Each column has a self explanatory heading identifying the type of data contained within it. The seven column headings are:

- Task ID
- Task
- Start
- Stop
- Duration
- Duration Source
- Resources

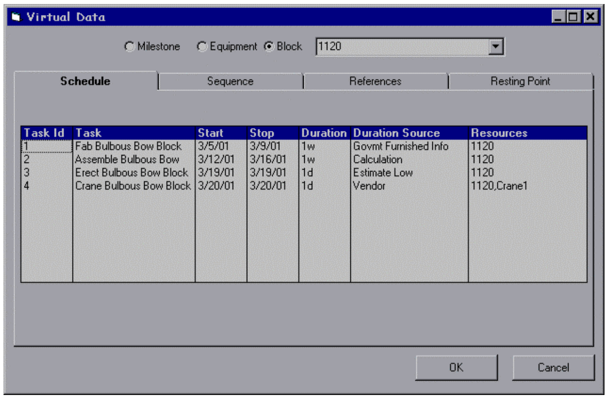

Figure 6. VSP Schedule Tab

The Sequence tab, Figure 7, displays the data relevant to the task's position or sequence within the project schedule. Included on this tab are columns that display the task's predecessor and successor information. A column for miscellaneous information is also included.

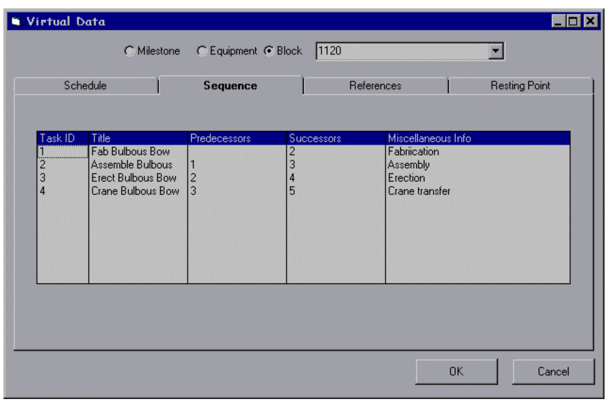

Figure 7. VSP Sequence Tab

The Reference tab, Figure 8, lists the tasks related to the filter selection and any background or referral information. The columns of data displayed are:

- Task
- POC (Point Of Contact)
- Phone
- Task ID
- Cost
- PWBS (Product Work Breakdown Structure)
- SWBS (Ship Work Breakdown Structure)

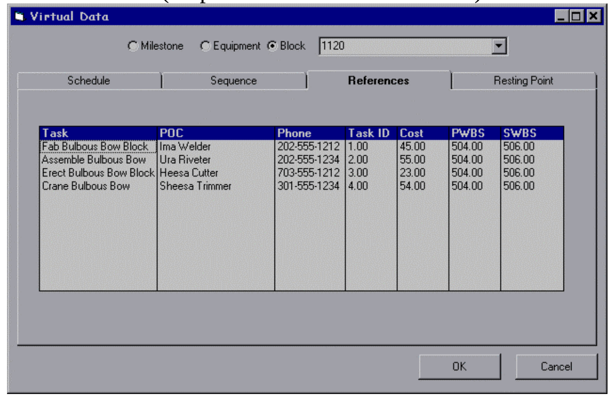

Figure 8. VSP Reference Tab

The Resting Point tab, Figure 9, provides both a visual and coordinate display of where the ship's blocks will be landed at the erection site. The resting points can be shown by individual block or by a group of blocks. For an individual block, the Filter section above the tabbed folder can be used to select the block of interest. The type of groups can be selected either by zone or for the entire ship. The display of zone resting points is done by clicking the mouse over a particular zone. All resting points and their coordinates relating to that zone will then be shown on the list box.

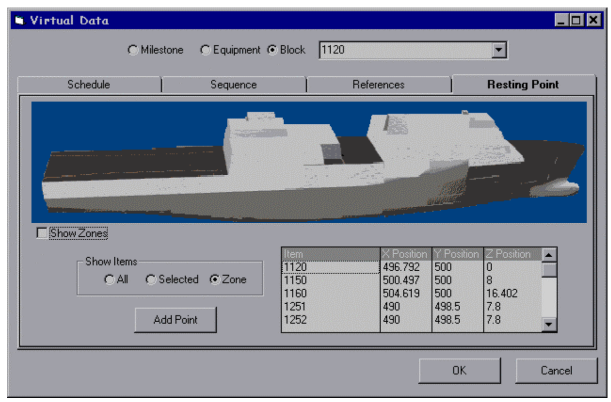

Figure 9. VSP Resting Point Tab

If the user is not familiar with the applicable zones, the Show Zones check box, Figure 10, can be clicked and the zones will be overlaid on the ship diagram. The XYZ position of the item's resting point can be edited as required. Clicking the Add Point button will create a new resting point for the user to enter the appropriate coordinates for.

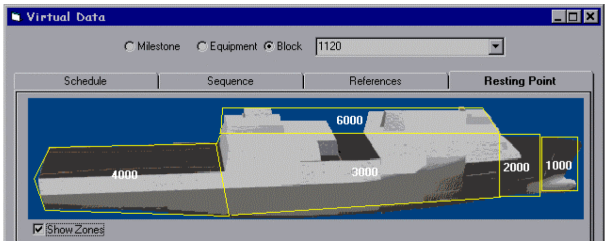

Figure 10. Show Zones Check Box

The **Virtual Ship Production** product also provides controls that allow the user, or VSP system administrator, to change some of the low level settings that affect the look and feel of the visual rendering. The controls for these settings are accessed by clicking on the Settings tool button on the Main Form, Figure 11. Doing so brings up the Setting Central form.

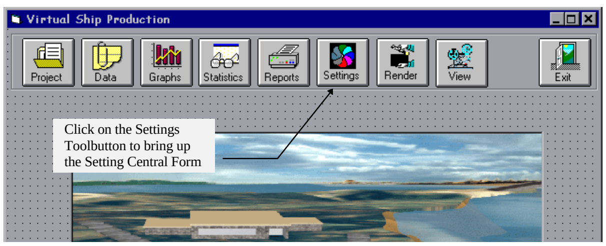

Figure 11. VSP Settings Tool Button

The Setting Central form is a tabbed form that segregates the different classes of data. The tabs are Areas, Queue, Week and Deltas.

The Areas tab allows the administrator to modify or add staging areas. Editing is done in typical word processing fashion by highlighting the value to be changed and using cursor keys to delete or change the entry. Adding a value is done by moving the cursor to a blank row and typing in the values.

The Queue tab is very much like the Areas tab in that it displays the names and coordinates of the queue positions. Editing and adding values for the queues is also done in the same manner as the Areas tab.

The Week tab allows the administrator to alter the positions and set the timing of the 'week buttons.' The following data entry points are provided for each position (i.e. in and out): X position, Y position, Z position, and Timing.

The Deltas tab is where the system administrator is able to fine tune the rendering process of the **Virtual Ship Production** system. The five sub-areas are:

- Hoist Point
- Time Deltas
- Miscellaneous Deltas
- Hide Point
- Abbreviate Milestones

The Hoist Point sub-area is where the coordinates of the crane hoist point is set. In addition to the X-Y-Z values, the timing or duration of the hoist event is entered in this sub-area.

The Time Deltas area is where the delay frame values for the following events are entered: leave, elevate, center point, final, reschedule. These events are described in Table XVI.

Event	Description
Leave	The number of days a block or piece of equipment is delayed before being elevated out of the staging area.
Elevate	The difference between 'elevate' and 'leave' is the time (in days) required for a block or piece of equipment to move from the staging area to the elevate point.
Center Point	The difference between 'center point' and 'elevate' is the time (in days) required for a block or piece of equipment to move from the elevate point to the center point.
Final	The difference between 'final' and 'center point' is the time (in days) required for a block or piece of equipment to move from the center point to its final resting point at the erection site (or, for certain equipment, the assembly building).
Reschedule	The minimum number of days the schedule for lifting a block or piece of equipment from the staging area is delayed due to a scheduling conflict.

Table XVI. Time Delta Events

The Miscellaneous deltas apply to other various functions in the rendering process. They are identified in Table XVII.

Function	Description
Milestone Time	The duration, in frames, of a milestone show event.
Elevate Height	The height in coordinate values to elevate an item above the staging area.
Hour/Frame	The number of hours per frame represented by the rendering.
Frame Default	The number of frames used if no other delta applies.
Reserved	Open for future enhancements.

Table XVII. Miscellaneous Deltas

The Hide Point sub area is where the coordinates for the hide point are entered. The Hide point is where blocks or pieces of equipment are pre-staged out of view in the rendering, just before they are moved to a staging area. The timing text box is where the time value or delay, by frame, for pre-staging is set.

The Abbreviate Milestones check box is used to set whether a fixed period of time is used for milestones or whether their actual time of duration is used. This feature is generally used when there are numerous milestones that precede any building activity. When checked, the milestones will be shown at fixed periods, according to the milestone timing set, instead of their relative time and thus shortening the inactive period of the rendering (i.e. the period during which construction activities are not visually being displayed).

Element Classification And Cost Entry Data Points. In order to accommodate the functionality offered by the Product Work Breakdown Structure (PWBS) and Ship Work Breakdown Structure (SWBS) classification system, as well as the potential linkage of data between this project's product and the Product Oriented Design and Construction (PODAC) Cost Estimating Model currently under development, a PWBS, SWBS and cost data entry point for each event tracked by the product model is included in the 'Virtual Data - References' template. The direct importance on the project's product of these entry points is that they provide the ability to track costs by their associated products and events in a time or calendar format. This will allow the user to create prospective expenditure schedules and graphs, as well as comparative (actual versus proposed) ones.

The exact code that will be used to identify each individual type of product in accordance with the PWBS breakdown structure is currently being developed under the Mid Term Sealift Ship Technology Development Program. The coding used for the SWBS data entry point, on the other hand, is in accordance with the current NAVSEA SWBS coding system.

Visualization Model

The shipyard depicted during the visualization process of the ship construction program is a generic shipyard that shows the minimum amount of information required to visually convey the merits of the viewed ship construction program. As such it contains one dry dock, twelve block staging areas, six equipment staging areas, a block queuing area, an equipment queuing area, and an assembly building. In addition to these items a stainless steel colored placard is located at the top of the screen over the shipyard. Upon this placard the ten milestones and miscellaneous events from the ship's Master Construction Schedule, as identified in the paragraph titled **Milestones/Miscellaneous**, are displayed as they occur. Each one is depicted as a raised, stainless steel colored button with black lettering.

The model's clock is also displayed on the placard in addition to the ten buttons. It is located at the bottom right hand corner and consists of two buttons; one labeled 'Week', and the other the appropriate numerical symbol (i.e. 1, 2, 3, etc.). Although visually the time is progressing by two hour intervals, the time units associated with an event can also be adjusted by the user through the **Virtual Ship Production** interface.

The block staging area contains a maximum of 12 lots that can be utilized by the ship production program. The exact number that will be used is dependent on the shipyard that is being modeled, and requires input by the user. Although the lots remain on the screen during the visualization process when they are not used, they are also not loaded with blocks. In this way they can be thought of as resources, for they are used only when available, and the actual number available does affect the outcome of the ship production program.

Associated with each staging area is a queue line, or area. These queues are included in the product model's visualization process in order to help convey the merits, or pitfalls, associated with the Master Construction Schedule being displayed. Along with the staging area lots, they can be used for visually determining if a production plan underutilized a shipyard's resources, or over utilizes them. If the latter is occurring then work in process (WIP) is also occurring. This is seen when the lots associated with the queuing area begin to be loaded with blocks, or equipment, waiting to arrive at the staging area. A good example would be when the schedule indicates that there are 16 blocks in the staging area. In this case, all twelve lots are being used, and there will also be four blocks shown in the queuing area. Under utilization of the shipyard resources, on the other hand, can be seen when the available lots in the staging areas are never fully utilized (i.e. there is always at least one lot that is empty). Another way to determine these characteristics of a construction plan is through the report option available in the project schedule and database software. Although not as visually appealing, reports using this option are able to deliver much more detailed information.

The assembly building is included in the visual display of the shipyard to show where some of the equipment might go after arriving in the shipyard. A good example of this is the steering gear. At the conclusion of the RIP process, as determined by the Master Construction Schedule, each gear is shown visually arriving in the equipment staging area and then traveling and disappearing into the assembly building. In this way they are visually shown as being joined to the block during its assembly phase instead of landed in the block after it has been erected.

The specific start/stop dates for the element moves (i.e. blocks and equipment) identified in the visualization sequence were determined by utilizing certain task start and stop dates as determined by the project schedule file. The specific tasks and date identifiers utilized are listed in Table XVIII.

Task or Event	Date Identifier Utilized	Visualization Movement Relationship
Block Assembly	Actual End Date	Arrival of the Block in the Block Staging Area
Block Erection	Actual Start Date	Departure of the Block from the Block Staging Area
Equipment RIP	Actual Start Date	Arrival of Equipment in the Equipment Staging Area
Equipment Landing	Actual Start Date	Departure of Equipment from the Equipment Staging Area

Table XVIII. Material Flow Determination Criteria

A snap shot of a demonstration run of the **Virtual Ship Production** product is shown in Figure 12. This snap shot is taken from a camera angle on the stern of the ship looking forward instead of the default position off the starboard side looking inboard. This change in camera position was made to demonstrate the flexibility of the visualization software's rendering process. By specifying the XYZ coordinates for the camera in the rendering process setup, the user can easily change the view of the ship construction process being displayed to suit particular needs.

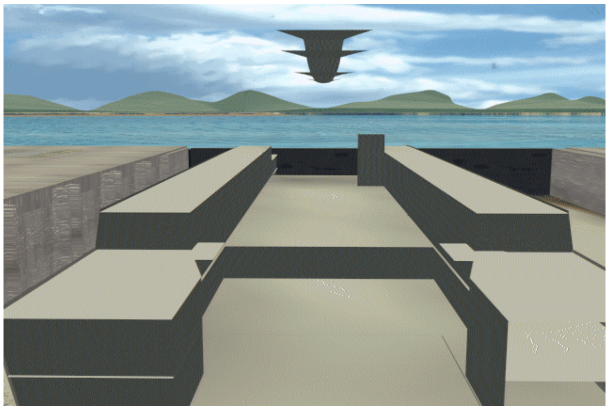

Figure 12. Stern View Of Ship Construction

Block Break Visualization. During the project, the visualization software was also used to view and print the graphical images of the equipment and individual blocks; the latter was also viewed by sub-zone in an exploded and unexploded format. This capability was found to be very useful in helping to verify the block break descriptions. Some samples of this capability are provided in Figures 13 and 14. Labels have been attached to the blocks in these figures in order to help identify them.

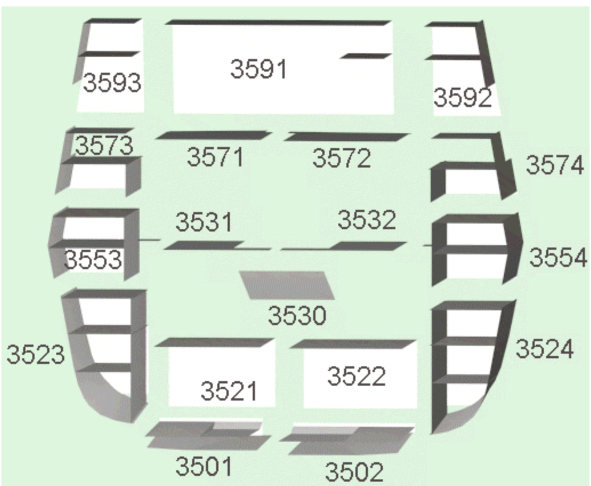

Figure 13. Exploded View Of Sub-Zone 3500

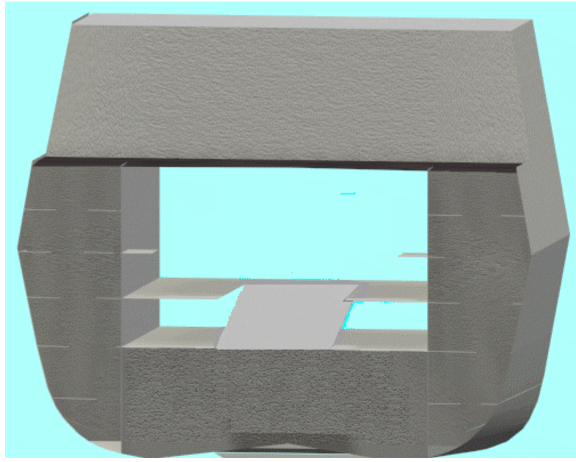

Figure 14. Solid View Of Sub-Zone 3500

Special Options

In order to provide user functionality to the **Virtual Ship Production** product a couple of special options were also created or designed into the product. These options include tools and/or capabilities in the following two areas: task filtering and risk assessment.

Task Filtering. An important feature of any scheduling or management tool is its ability to filter information as required or needed. This is especially true when managing large projects like ship construction, where many types, or groups of information are often placed together in a single schedule, report, or file.

In this project, the ship construction project file contains both task and resource related information. These two classes of information type can be further divided into numerous sub-classes each of which tracks a specific aspect of the applicable ship production program. In order to assist the program manager in the retrieval of this information, a number of filters were added to the default list provided by the project scheduling software. These additional filters were created by using the filter editing capabilities of the project scheduling software and entering the relevant information in the appropriate project file data columns. A brief description of each of these additional filters is provided in Table XIX.

Risk Assessment. Although schedules do aid in the organization and management process of any project, they are not necessarily accurate. Because the information entered into a schedule is only as accurate as its source is able to make it, the information received from a schedule is rarely if ever one hundred percent accurate. This is especially true for the dates and durations of the events being tracked within a schedule. Quite often these factors are guesses and estimates based on past performance, or the actual past performances of similar processes. They are not guaranteed. In light of this, the capability of creating schedules based on statistical distributions is highly desired. When this is done, and a number of iterations are accomplished, a risk assessment of the schedule is performed. The result is a compilation of schedules ranging from the most probable to the least probable, and a number of possible critical paths.

In order to allow the user to be able to add this functionality to his or her management project, **Virtual Ship Production** has been organized in a manner that allows the incorporation of a couple of different risk analysis systems. These systems provide project management functionality that allows the user to assign statistical distributions to selected task events and event duration. With this capability the user is able to perform a number of iterations on the schedule in question, and determine the most to least likely schedule scenarios, project duration, critical paths, and critical path tasks.

Filter Name	Filter Description
Block	Show all tasks associated with the specified block number.
Filter Out Process/Stage	Show all tasks that are not associated with the specified process or stage.
Process/Stage and Block	Show the task that contains this specified process or stage for the identified block number.
Process/Stage & Zonal/Unit Range	Show the tasks that contain this specified process or stage for the identified range of zones or units.
Process/Stage	Show all tasks associated with the specified process/stage.
Zonal/Unit Range	Show all tasks associated with the specified range of zones or units.

Table XIX. Filters

Resource Load Leveling

In addition to the above mentioned special options, the project scheduling software also offers three methods of determining project durations. These methods are fixed-duration scheduling, resource-driven scheduling, and a combination of the two. Fixed-duration scheduling is strictly time based using task durations that are interlinked with the scheduled task start and stop dates. In resource-driven scheduling, however, the task durations are based on the work content of the task and the amount of resources assigned to it. When a combination of these methods is used some of the task durations are determined by one method, while the remaining task durations are determined by the other method.

As indicated above, the application of resource-driven scheduling allows a project schedule to be tailored to fit the actual resources available for performing the assigned tasks. This capability of the project scheduling software lends itself well to the scheduling and analysis features of the **Virtual Ship Production** product. Through the application of resource-driven scheduling, ship production schedules can be analyzed with regards to the specific capabilities of a shipyard. When resources are applied to tasks at a degree greater than their capacity, however, resource load leveling conflicts occur. Fortunately, the project scheduling software is able to identify when this happens, and immediately notifies the user. The user, or project manager can then manually, or with the assistance of the options provided within the project scheduling software, resolve the conflict by leveling the resources, and thereby adjusting the schedule.

In using the **Virtual Ship Production** product it is recommended that at a minimum resource-driven scheduling be applied to the crane transfer tasks. The utilization of this capability on this event will not only help to identify where resource load leveling conflicts occur, but also as a minimum produce a schedule that is representative of a shipyard's crane capacity for landing blocks and equipment at the erection site.

Visualization Technology Conclusions

The visualization process developed for the **Virtual Ship Production** product is a tool that can be used by all levels of the shipyard management team and program acquisition team. The Ship Acquisition Program Manager (SHAPM) can use this tool to manage the project, to monitor progress, evaluate construction scenarios and generally keep Integrated Product and Process Development (IPPD) teams completely abreast of the latest construction process as the ship acquisition process takes place. This schedule/visualization tool is also useful for high level presentations at NAVSEA or command level briefings.

Other specific areas in which computer visualization can be used as a tool in shipbuilding include:

- Linkages to shipyard detail schedules:
  - **(a)** Engineering plan schedule
  - **(b)** Outfitting
    - Pallet schedule
    - Long Lead Time Material (LLTM) schedule
    - Shop schedules - Marshaling yard
  - **(c)** Hull steel unit schedules
    - Shop
    - Platen
    - Gate/work station
  - **(d)** Erection schedule
    - Grand units/Blocks
    - Shipway
  - **(e)** Zones - on ship
    - Zone outfitting schedules
- Present new production sequences to show rescheduling influences
- Progress tracking with color presentations for shipyard internal use
- Training tool for production planners, superintendents and foremen
- Process lane resource planning, and throughput/bottle neck identification
- Training tool that provides an animated demonstration of the erection sequence
- Progress presentations, and expected progress presentations, for government Quarterly Progress Reviews (QPR's)
- Internal management presentations to do "what ifs" at the vice president level and higher
- Detail tracking of completion at the work station or gate level with process lane/work station simulations
- Gate presentation for supervision showing the manner in which the unit will be sitting for welding and for outfitting in their gates

CONCLUSIONS

Many conclusions can be drawn from the previous sections. The basic premise of these conclusions though should be that if utilized properly, simulation based design, and visualization technology, offer an extremely high return on investment. With a very wide scope of application, from the production planning function and the planning efforts through to the vice presidential level for high level presentations, these two technologies are an aid to all levels of the shipyard management team.

A specific area in which these techniques would be helpful to a shipyard is in the development of their build strategy. This is because the build strategy includes within it a sequence of erection which in turn influences all of the upstream production department involvement and scheduling decisions. A ship's build strategy and resultant sequence of erection therefore are strongly influenced by the various aspects of the shipyard environment. These aspects include the building and erection site availability, as well as material availability, and concerns in the level loading of human resources and cash flow. It is with these problems and concerns in mind, that visualization and the benefits of computer simulation aides are considered most helpful in the planning process.

As indicated, both simulation based design and process flow simulation are wonderful tools for design and analysis purposes. When utilized properly they offer the opportunity to analyze design decisions for bottlenecks and inefficiencies early in the design cycle where changes and modifications can still be made. This capability allows the design team to produce an optimized, or highly efficient design, with a high degree of confidence. Another benefit of these design techniques is that when a design is selected for use its performance characteristics will be known. Modifications or improvements to existing designs can also be analyzed for their effectiveness through the application of process flow analysis. The only drawback with this technique of design and analysis is that its results are only as accurate as the data used to develop the simulation model.

Unfortunately, if these processes are applied late in the design process, such as near the completion of the contract design stage, the implementation of any modifications to the design based on the results of these studies is remote. Any and all suggested modifications to the design would have to be carefully evaluated; weighing the benefits of the modification(s) against the cost impact of implementing them. Because of this, it is recommended that in all future ship design programs process flow design and analysis methods be applied as early as possible in the ship design process in order to obtain the maximum benefits offered by this technique.

ACKNOWLEDGMENT

This paper is based upon work performed for the US Navy's Affordability Through Commonality (ATC) Program operated under the Naval Sea Systems Command (NAVSEA). ATC's objective is to reduce the total life cycle cost of ownership of Navy ships through increased equipment standardization, the use of common modules with standard module interfaces, and process simplification including modular ship architectures with zonal distributed systems and a generic production oriented build strategy.

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